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NRL Report 7051
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Interference From HF Radar
[Unclassified Title]

F. E. Boyd and B. N. Navid

Radar Techniques Branch
Radar Division

March 24, 1970

[redacted]

NAVAL RESEARCH LABORATORY
Washington, D.C.

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ABSTRACT
(Unclassified)

Interference to communication reception near an HF radar is dependent on many factors. It is shown that the most important of these that can be controlled is the pulse shape of the radar. Under optimum conditions, acceptable reception should be possible with frequency separation as little as 21 kHz from the proposed radar. At separations up to 450 kHz, only occasional interference problems are expected.

Measurements with the NRL HF research radar indicate that the radar is undectectable beyond 200 kHz from the radar frequency. The radar peak power was 1.83 MW, a 270-μsec pulse essentially cosine squared was employed, and the receiver was at a distance of 16.22 km across the Chesapeake Bay.

PROBLEM STATUS

Work is completed on this phase of the problem and is being continued on other phases.

AUTHORIZATION

NRL Problem R02-42
USAF MIPR 64-3412

Manuscript submitted January 7, 1970.

INTERFERENCE FROM HF RADAR
(Unclassified Title)

INTRODUCTION

(U) Most HF radars, in existence or contemplated, use very high-power pulses and operate in a highly congested part of the radio spectrum. The combination of these two factors leads to a possibility of a bad interference problem. Even though measures are taken to restrict the bandwidth of HF radars, there is still a certain amount of inevitable interference. The study reported here was undertaken to evaluate the potential interference to be expected in the vicinity of a particular radar, but it is expected that the results will be typical for any HF radar apt to be built within the next decade or two.

(U) For many reasons, the problem is best handled by an analytical approach. Perhaps the most compelling reason is that all HF radars, both existing and proposed, differ widely, thereby making it difficult to apply the experience from one to another. The differences are apparent in the power levels, antenna gains, pulse shapes, antenna patterns, and antenna sites. There is also considerable difficulty and time expenditure involved in conducting controlled tests of the nature reported here. What follows therefore is primarily a theoretical analysis. Following this, the results of a simple and short experiment are presented to supplement the analysis.

PULSE FREQUENCY SPECTRUM

(U) Most HF radars make use of a cosine-squared pulse envelope to limit the bandwidth. The beginning and end of the $\cos^2$ pulse is often eliminated for many practical reasons. We will call this a truncated $\cos^2$ pulse shape. It has a frequency spectrum which has been computed using the formula

$$G(f) = \frac{At_0}{K2\pi\alpha(1-\alpha^2)} \left\{[1-\alpha^2(1+\cos K\pi)]\sin K\pi\alpha + \alpha\sin K\pi \cos K\pi\alpha\right\},$$

where t_0 = pulse length after truncation (see Fig. 1),

α = $t_0 f/K$,

f = frequency referred to the carrier or center frequency,

K = the fractional part of the $\cos^2$ pulse left after truncation,

A = an amplitude factor; to normalize, let $\frac{At_0}{K2\pi} = 1$.

(U) A tabulation of the frequency spectrum up to 20 kHz for a 250-μsec pulse is given in Table 1 (and plotted in Fig. 2), along with the spectrum of a rectangular pulse and a $\cos^2$ pulse for comparative purposes. The overall lengths of these pulses are equal. In Table 1 and the examples that follow, the truncated pulse has been formed by truncation

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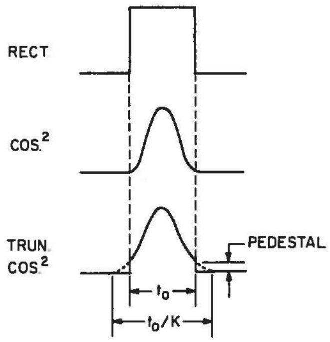

Fig. 1 (U) - Pulse length relationship. Spectra of these pulses are given in Table 1.

Table 1 (U)
Frequency Spectra of Several Pulse Shapes*

Frequency (Hz)	Rectangular Pulse Shape (dB)	Cos Sq. (dB)	Truncated Cos^2 (dB)	Cos Sq. (V)
0	0.00	0.00	0.00	1.00000
500	-0.22	-0.09	-0.13	0.98527
1000	-0.91	-0.35	-0.52	0.94209
1500	-2.11	-0.79	-1.18	0.87333
2000	-3.92	-1.42	-2.12	0.78353
2500	-6.55	-2.25	-3.37	0.67845
3000	-10.45	-3.27	-4.97	0.56459
3500	-17.13	-4.52	-6.96	0.44866
4000	-999.00	-6.00	-9.45	0.33697
4500	-19.31	-7.79	-12.58	0.23501
5000	-14.89	-9.89	-16.65	0.14702
5500	-13.40	-12.39	-22.41	0.07578
6000	-13.46	-15.40	-32.97	0.02246
6500	-14.85	-19.15	-37.55	-0.01326
7000	-17.81	-24.10	-29.62	-0.03304
7500	-23.75	-31.76	-28.06	-0.03955
8000	-999.00	-999.00	-28.85	-0.03610
8500	-24.83	-35.75	-31.62	-0.02625
9000	-20.00	-32.17	-37.46	-0.01340
9500	-18.14	-31.48	-65.88	-0.00051
10000	-17.90	-32.30	-39.84	0.01018
10500	-19.01	-34.42	-35.27	0.01725
11000	-21.74	-38.08	-33.94	0.02010
11500	-27.46	-44.68	-34.46	0.01892
12000	-999.00	-999.00	-36.77	0.01451
12500	-28.18	-47.04	-41.89	0.00804
13000	-23.19	-42.80	-61.37	0.00085
13500	-21.20	-41.53	-44.78	-0.00577
14000	-20.82	-41.85	-39.34	-0.01079
14500	-21.82	-43.50	-37.36	-0.01355
15000	-24.43	-46.75	-37.20	-0.01380
15500	-30.05	-52.98	-38.60	-0.01174
16000	-999.00	-999.00	-42.05	-0.00790
16500	-30.59	-54.69	-50.37	-0.00303
17000	-25.52	-50.16	-53.99	0.00200
17500	-23.45	-48.62	-43.92	0.00637
18000	-23.01	-48.70	-40.51	0.00944
18500	-23.93	-50.12	-39.34	0.01079
19000	-26.49	-53.16	-39.71	0.01034
19500	-32.05	-59.19	-41.66	0.00826
20000	-999.00	-999.00	-46.06	0.00498

*Pulse length, 250 μsec; fraction of cos^2 pulse left after truncation, 80%; frequency interval, 500 Hz; highest frequency, 20 kHz; pedestal, -20.40 dB.

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at a level 10% above zero. To illustrate the spectrum over a larger span, only the envelope of the spectrum has been plotted in Fig. 3. Some of the computed values are plotted as individual points.

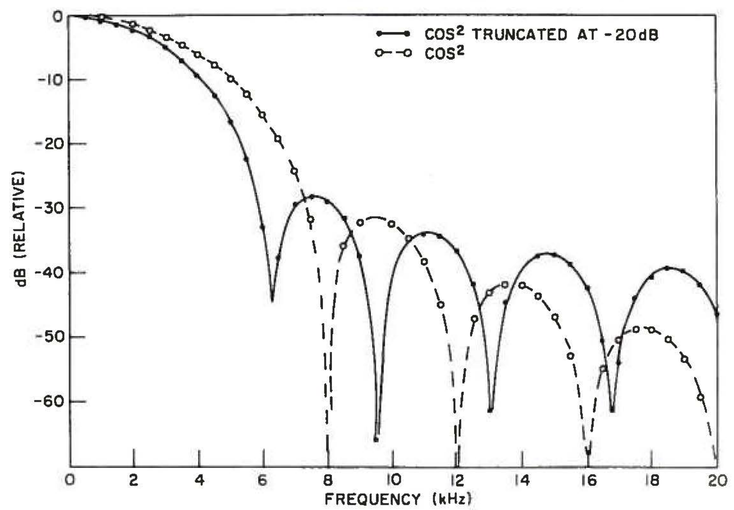


Fig. 2 (U) - Frequency spectrum of pulses 250 μsec long. For other pulse lengths multiply the frequency scale by 250 divided by the pulse length in microseconds.

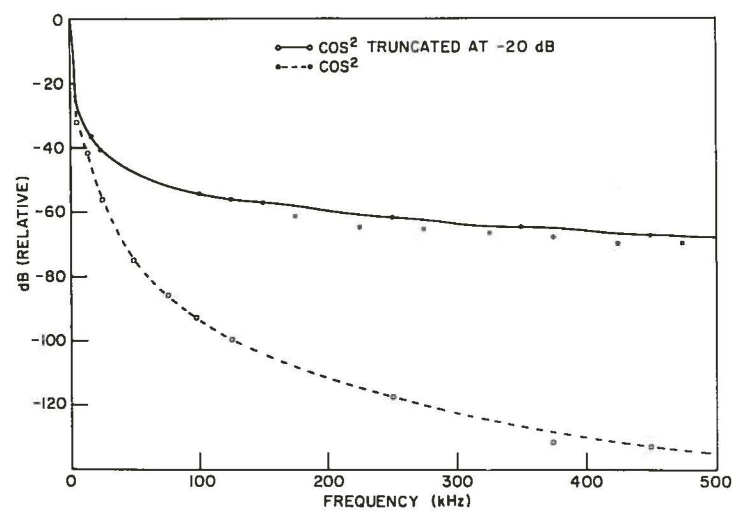


Fig. 3 (U) - Frequency spectrum envelope of pulses 250 microseconds long

(U) In conjunction with truncation of the $\cos^2$ pulse, it is also of interest to determine the power contained in the pulse. This was related to the power in a rectangular pulse of the same length according to the following:

$$\text{Power ratio} = \frac{3}{8} + \frac{1}{2K\pi}\left(\frac{\cos^2 \frac{K\pi}{2} \sin K\pi}{2} + \frac{3}{4} \sin K\pi\right).$$

The results are given in Table 2.

Table 2 (U)
Dependence of the Power Rates on the Pedestal Height

Truncation Ratio	Pedestal (dB)	Power Ratio
1.000	-999.00	0.3750
0.980	-60.12	0.3827
0.960	-48.08	0.3906
0.940	-41.05	0.3989
0.920	-36.08	0.4076
0.900	-32.23	0.4167
0.880	-29.09	0.4261
0.860	-26.45	0.4360
0.840	-24.17	0.4463
0.820	-22.18	0.4570
0.800	-20.40	0.4683
0.780	-18.81	0.4800
0.760	-17.36	0.4922
0.740	-16.04	0.5050
0.720	-14.83	0.5182
0.700	-13.72	0.5319
0.680	-12.69	0.5461
0.660	-11.73	0.5609
0.640	-10.84	0.5761
0.620	-10.01	0.5917
0.600	-9.23	0.6078
0.580	-8.50	0.6243
0.560	-7.82	0.6411
0.540	-7.18	0.6582
0.520	-6.58	0.6757
0.500	-6.02	0.6933
0.480	-5.49	0.7111
0.460	-4.99	0.7290
0.440	-4.53	0.7470
0.420	-4.09	0.7649
0.400	-3.68	0.7826
0.380	-3.30	0.8003
0.360	-2.94	0.8176
0.340	-2.61	0.8346
0.320	-2.29	0.8512

RECEIVER CHARACTERISTICS

(U) Of prime interest is the selectivity characteristics of communications receivers commonly used. The selectivity curves of two such receivers are shown in Fig. 4. The data on the Redifon Type R.408 were obtained from the manufacturer's literature;* data on the U.S. military type R-390A/URR receiver are from direct measurement of the unit used in this experiment. Data given are for both receivers in the 8-kHz bandwidth position. Widening of the selectivity curve beyond the -60 or -70 dB points is probably dependent on the dynamic range of the receiver.

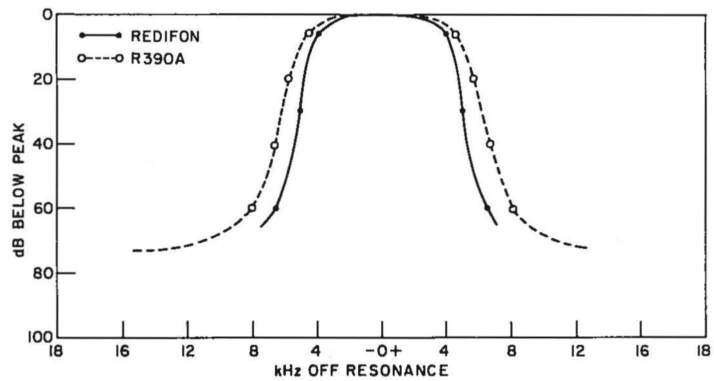


Fig. 4 (U) - Selectivity of radio communications receivers. Bandwidth setting = 8 kHz.

INTERFERENCE SAMPLE CALCULATIONS

(U) There is a multitude of variables involved in any specific interference calculation. In the following, an attempt is made to approximate conditions which prevail most often. It must be remembered that any specific instance could vary considerably from the assumed conditions.

(U) The desired signal is assumed to emanate from a Coast Guard radio station 93 km (50 naut mi) from the receiver. The power utilized by Coast Guard stations varies considerably among stations but generally ranges from 125 W to 50 kW. We will assume that a typical low-power station uses 500 W, a dipole antenna, and double sideband modulation (A3 modulation). Similarly, a high-power station uses 10 kW, a monopole antenna, and frequency-shift radio-teletype (RTTY) modulation. The voltage gain of the dipole is 1.28 and the monopole is 1.81.

(S) The radar for this example has a maximum average output of 200 kW. The average output is used, since this is the peak power in the center frequency of the spectrum. A representative pulse length is 1 msec. Shorter pulse lengths will probably be used infrequently and for special purposes. The radiation center of the antenna at 8 MHz lies 3100 ft from a shore line. Navigable waters for large ships commence 10 km beyond the shore, so this distance from the radar is assumed. Radiation toward a shipborne receiver at this range will have an angle of departure of zero degrees. The radar antenna gain for

*Redifon Limited, Marine Division, Hardwicks Way, London, S.W. 18.

vertical polarization is 26.5 dB at the peak of the beam but will be 20 dB or less at zero degrees elevation. If horizontal polarization is used, the field will be considerably less.

(U) The effect of propagation, either ground wave or sky wave, will be completely neglected. This is justified for several reasons. The radar is close enough to the receiver that a primarily line-of-sight path exists. Propagation losses over the 93-km path from the Coast Guard station will be quite variable, ranging anywhere from 0 up to 10 dB under normal conditions. It is not felt that this will make a significant change in the results.

(U) It is necessary to compute the signal levels of the desired (Coast Guard) and interfering (radar) signals in order to determine the separation required for reliable reception of the desired signal. Field strength is calculated from

$$E, = \frac{\sqrt{30\,P}}{D} G$$

where E = field strength in volts per meter,

P = radiated power in watts,

D = distance in meters,

G = antenna gain in voltage relative to an isotope.

(S) The results are given in Table 3. The separation required is determined by referring to Fig. 3, remembering to make the 1/4 correction for the four-times-longer pulse. The sideband must be down an amount equal to the interference to the desired signal ratio given in column 8 of Table 3. Interference from the radar carrier and higher-level sidebands is eliminated by the receiver selectivity. An exception to the latter statement occurs in the rare case where the separation required approaches the receiver bandwidth. In that case, a slightly larger separation is needed.

(U) In reviewing the results of Table 3, it should be noted that the very distant sidebands are generated by the sharp "corners" on the pulse. (From another viewpoint these sidebands are primarily due to the rectangular portion of the pulse.) In a practical application, it is difficult to obtain these "corners," and as a matter of fact, it is undesirable from a spectrum-conservation viewpoint. Any time the sidebands required are -60 dB or smaller, one should suspect that the results depend entirely on the design and care exercised in producing the prescribed pulse shape. From Fig. 3 it can be seen that a perfect $\cos^2$ pulse spectrum is much lower for sidebands beyond 20 kHz. Therefore, the result of column 9 is pessimistic, and the true answer lies between the values of columns 9 and 10.

RESULTS OF MEASUREMENTS

(S) Measurements of field strength and interference were made using the HF research radar situated at the Naval Research Laboratory's Chesapeake Bay Division. During the measurement period, the radar had the following characteristics:

Peak power 1.83 MW;

PRF, 180 Hz;

Pulse length, 270 μsec.

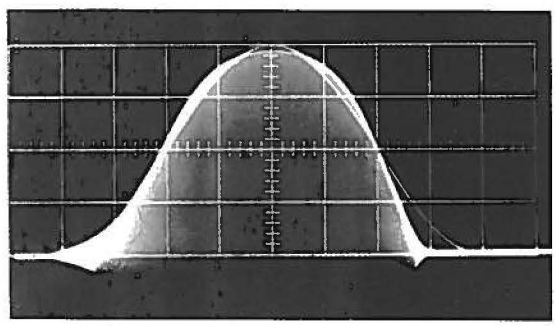
Table 3 (S)
Field - Strength and Frequency - Separation Computation

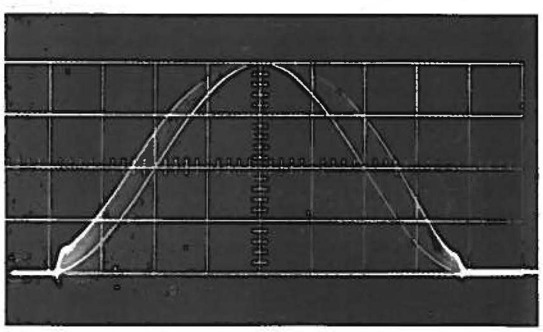
Col.→ Stations	1 Power Radiated (kW)	2 Distance (km)	3 Antenna Gain, Voltage Ratio	4 Field Strength V/m	5 Interference/ Signal* (dB)	6 Modulation Type	7 Required S/N† (dB)	8 Total Separation Required‡ (dB)	9 Separation for Truncated $\cos^2$ Radar Pulse (kHz)	10§ Separation For $\cos^2$ Radar Pulse (kHz)
Coast Guard, high power	10	92.5	1.81	10.71×10^{-3}	47	FSK	6	53	21	7
Coast Guard, low power	0.5	92.5	1.28	1.7×10^{-3}	63	A3	15	78	450	14
Radar#	200	10	10	2.45	-	-	-	-	-	-

*If the radar and Coast Guard were on the same frequency, this would be the value at the receiver site.
†These are the minimum operating S/N ratios for the class of commercial service given in col 6 (Ref. 1, p. 551).
‡The sum of col 5 and 7.
§Columns 9 and 10 give the separation required to achieve the S/N ratio of col 7.
#The radar pulse length was 1 msec.

Of the two pulse shapes shown in Fig. 5 which were used, only the $\cos^2$ pulse is a fair approximation. It is obvious from Fig. 5 that the truncated $\cos^2$ pulse has a very slow rise time in the truncated part and the corners are severely rounded. Because of this there is practically no difference in the observations associated with the two pulses. The receiver measurements were made directly across the bay on Tilghman Island, a distance of 16.22 km from the radar. The R-390A receiver was connected to a 10-MHz dipole antenna oriented for the best reception of the radar.

(a) - $\cos^2$





(b) - Truncated cosine-squared

Fig. 5 (U) - Pulse shape of HF research radar. The graticule contains an engraved $\cos^2$ shape.

(U) Table 4 lists frequency separations and relative strengths of communication signals which produced good readable signal-to-interference levels. Equipment was not available to identify the signals, since they were all RTTY or multiplexed modulation. However, by measuring signal strength at the receiver terminals and comparing it to the radar signal, general agreement is noted with the theoretical computations. In addition, it was noted that the radar signal was not detectable (i.e., did not exceed atmospheric noise) beyond the limits given in Table 5.

Table 4 (U)
Signals Received Adjacent to the Radar Frequency

Radar Frequency (kHz)	Spacing of Communication Signal from Radar (kHz)	Radar to Communication Signal Amplitudes* (dB)
10087	18	65
10087	43	40
10087	49	60
13560	39	57.1
13560	80	52
13560	42	57.1

*Ratio of received signal strength of radar measured on the radar carrier frequency to the received signal strength of communication station measured on the communications carrier frequency.

Table 5 (U)
Measured Limits of Detectable Signal

Radar Frequency (kHz)	Pulse Shape	Detectable Frequency (kHz)	Total Frequency Span (kHz)
10087	$\cos^2$	9985-10226	241
10087	Truncated $\cos^2$	9940-10220	280
13560	$\cos^2$	13445-13705	260
13560	Truncated $\cos^2$	13340-13730	390

(U) The field strength of the radar signal was measured with a Stoddart Model NM-25T instrument in the peak position. The expected field strength was computed with the aid of a computer program prepared by the Environmental Science Services Administration (2). The measured and theoretical values in Table 6 agree within the accuracy of measurement, which is 3 to 4 dB.

Table 6 (U)
Radar Field Strength at Tilghman Island, Md.

Frequency (kHz)	Antenna Used			Computed Ground-Wave Loss Factor*	Field Strength in mv/m		
	Type	Absolute Gain			Computed		Measured
		(dB)	(V)		Free Space†	Result‡	
10087	Positionable Array	9.2	2.9	1.98×10^{-2}	1310	25.9	23.6
13560	Positionable Array	10.1	3.2	2.65×10^{-2}	1460	38.6	
13560	Fixed Array	19.4	9.3	8.74×10^{-3}	4240	37.0	90.0

*Computation based on horizontal polarization: permittivity, 80; earth conductivity, 1.5 mho/m; height of receiver, 16 m; height of transmitter, 96 m for positionable antenna (32 m for fixed antenna); effective earth radius factor, 1.333; and distance, 16.22 km.

†Free-space field strength in V/m $= \frac{\sqrt{30}\,\sqrt{P}}{D} G$.

‡The result is the product of the free-space field strength and the ground-wave loss factor.

CONCLUSIONS

(U) Interference to communication reception near an HF radar depends on many factors. It is shown that the most important of these that can be controlled is the pulse shape of the radar. The pulse shape of an operational radar must be carefully monitored and properly shaped if one wishes to insure minimum interference at all times. Separations of less than 450 kHz are expected to be adequate under most circumstances with the proposed radar. Separations as low as 21 kHz should be usable under ideal conditions.

(U) Measurements at Tilghman Island against the NRL HF research radar indicate that the radar is undetectable beyond 200 kHz from the radar frequency.

REFERENCES (U)

1. Laport, E.A., "Radio Antenna Engineering," New York:McGraw-Hill, 1952

2. Berry, L.A., and Chrisman, M.E., "A FORTRAN Program for Calculation of Ground Wave Propagation over Homogeneous Spherical Earth for Dipole Antennas," NBS Report 9178, U.S. Department of Commerce (Unclassified), Mar. 15, 1966

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13. ABSTRACT

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Interference to communication reception near an HF radar is dependent on many factors. It is shown that the most important of these that can be controlled is the pulse shape of the radar. Under optimum conditions, acceptable reception should be possible with frequency separation as little as 21 kHz from the proposed radar. At separations up to 450 kHz, only occasional interference problems are expected.

Measurements with the NRL HF research radar indicate that the radar is undetectable beyond 200 kHz from the radar frequency. The radar peak power was 1.83 MW, a 270-μsec pulse essentially cosine squared was employed, and the receiver was at a distance of 16.22 km across the Chesapeake Bay.

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Electromagnetic interference						
Electromagnetic field strength						
Pulse spectrum						
HF pulse transmitters						
Radar interference						

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